T-HEAD GROIN ADVANCEMENTS IN ONE-LINE MODELING (GENESIS/T)

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ABSTRACT: The GENESIS model has proven its capabilities in numerous projects worldwide for simulating shoreline change and longshore sediment transport on wave-dominated beaches. Even though the model has been made generally applicable to "almost arbitrary" configurations of shoreline shapes and structural measures, some important features are not yet represented. This paper describes a new major capability recently implemented in the model, representation of tombolos at detached breakwaters and T-head groins. Illustrative examples indicate promising results for this major enhancement to the model.

INTRODUCTION

Chronic erosion and an undesirable distorted hook-shaped shoreline are typically found on beaches located down-drift of inlet jetties where a dominant direction of longshore sediment transport exists. Dredged material or beach fill placed in such areas is rapidly transported away, with a substantial portion possibly moving into the navigation channel. If an ebb-shoal attachment bar forms, the beach between the jetty and the attachment bar may become isolated from natural sediment paths, increasing the erosional trend at the beach and further distorting the shoreline.

Several remediation measures have been proposed and implemented for reducing erosion and increasing the longevity of material placed in such hot spots. These include lengthening the down-drift jetty, placement of an external spur breakwater on the down-drift jetty, groin fields, detached breakwaters, T-head groins, and combinations. A quantitative tool is lacking for developing, designing, and comparing the functioning of such proposed solutions.

In its original version, the GENESIS shoreline-response model (Hanson 1989; Hanson and Kraus 1989; Gravens et al. 1991) allows calculation of shoreline response for a wide variety of coastal features and engineering activities, under the assumption that wave-generated currents dominate the longshore sediment (typically sand or sand-sized particles) transport. These features and activities include protective measures such as groins, jetties, seawall, beach fills, bypassing operations, and linear or point sources and sinks of

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sediment. Coastal structures and beach fill can be introduced in almost arbitrary numbers, locations, and combinations. Other processes included are wave transmission through structures, sediment passing through or by groins and jetties, wave diffraction from multiple structures and headlands, and multiple wave trains (e.g. wind waves and swell from different directions). However, the original GENESIS model also has limitations, of which a significant one is the lack of capability to represent tombolos. The present paper discusses preliminary results of recent enhancements of the GENESIS model regarding an algorithm for representing tombolos inside of T-head groins and detached breakwaters.

PROCEDURE

Representation of Tombolos. The boundary condition for representing tombolo formation at T-head groins and detached breakwaters (DBWs) is formulated analogously to that of a seawall in GENESIS as discussed in Hanson and Kraus (1986) and in Kraus and Hanson (1995). However, implementation of the tombolo constraint is more complex as it includes wave diffraction, blocking of previously open calculation cells, and transport of sediment on both the landward and the seaward sides of the structure. The tombolo concept implies that the beach can reach the structure but not further. As a calculation cell makes contact with the structure, the transport rate into that cell is adjusted to allow the excess sediment to remain in updrift cells. The procedure to do this must conserve sediment volume and preserve the direction of its transport.

The procedure is illustrated in Fig. 1, a plan view of an idealized beach protected by a DBW at an arbitrary moment in time. In the figure, the *x*-axis runs along the main trend of the shoreline, and the shoreline location *y* is represented by the length of each cell. Shoreline change at each cell is determined by the net flux of sediment over its two shore-perpendicular walls. A net influx (gain) produces beach accretion and a net outflux (loss) produces erosion. A tombolo has developed in Cell 7 in a previous time step. In the adjacent Cell 6, allowing the calculated influx Q_6 from Cell 5 to enter, the shoreline would advance beyond the DBW (Fig. 1a), which is not allowed.

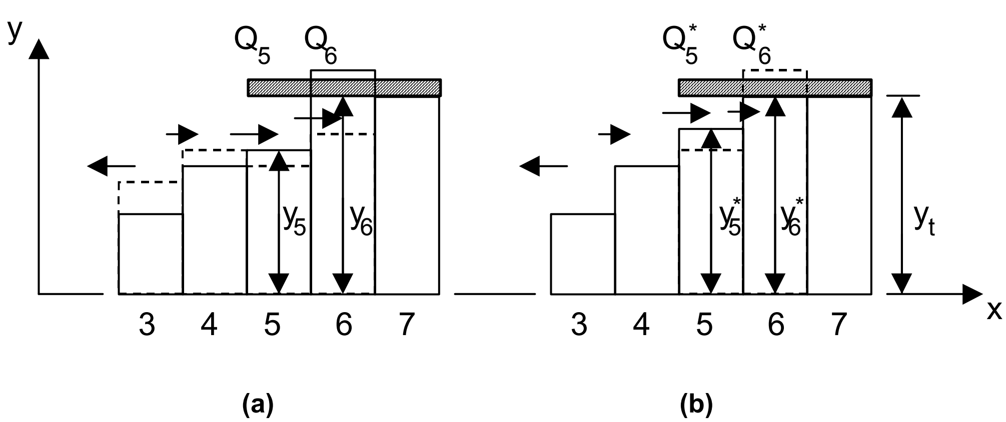

Fig. 1. Schematic plan view illustrating (a) initially calculated transport rates and shoreline location and (b) corrections near tombolo formation.

Thus, the initially calculated transport rate Q_6 must be adjusted to Q_6^* (Fig. 1b) to cause the shoreline to advance up to the detached breakwater but no further, giving $y_6^* = y_t$. With the new transport Q_6^* now going out of Cell 5, the shoreline location in this cell will be adjusted from y_5 to y_5^*. In this particular case, only two cells were recalculated. In the general case, the correction may be carried through any number of cells until the criterion that the shoreline may not advance beyond the DBW is not violated.

APPLICATIONS

Comparison with Physical Model T-head Groin Tests. Field data describing salient or tombolo development inside of T-head groins of detached breakwaters are rare. Available filed case studies typically give the near-equilibrium shoreline configuration but not the temporal coastal evolution or the associated wave time series. Thus, as a substitute, results from a movable-bed physical model were examined. In a previous study, Hanson and Kraus (1991) compared predictions of the GENESIS model, with results obtain in a physical model (Hashimoto et al. 1981). Hashimoto et al. evaluated four shore-protection designs for winter wave conditions at a site facing the Pacific Ocean of Japan by using a large wave basin (16 by 20 m) and a sand bottom. The structure dimensions and spacing were modeled at 1/50 scale. The basin configuration is shown in Fig. 2.

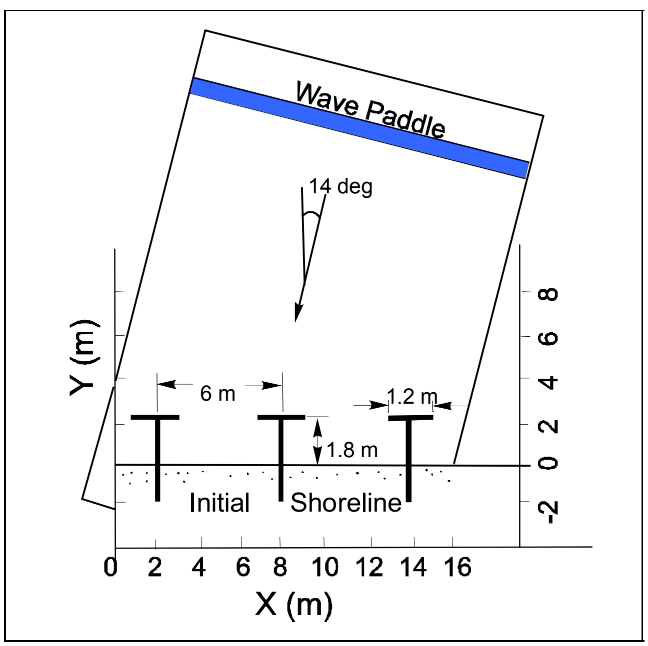

Fig. 2. Configuration of physical model of Hashimoto et al. (1981).

Two of the cases, Case 1 with three groins of equal length and Case 3 with three detached breakwaters located at the same distance offshore as the tips of the three groins, were reported in the previous study of Hanson and Kraus (1991). Good agreement was found between physical and numerical model results.

To illustrate the new capability with the improved representation of T-head groins, Case 4 with three T-head groins was studied here. This case is a superposition of Cases 1 and 3. Of particular value for evaluating models was that the beach was aligned at a 14-deg angle to the wave generator, producing obliquely incident waves and a predominant direction of longshore transport.

The design initial shoreline ($y = 0$) was located 4 m from the end of the basin, and the entire beach from - 4 m to + 10 m was built of sand (median grain size, 0.27 mm). The bottom profile configuration replicated the field site, with the foreshore going from the still-water shoreline to a depth of 10 cm on a 1/10 slope; then tapering to a gently sloping beach to a depth of 20 cm located 8 m from the shoreline. For two more meters the slope tapered to the bottom (-40 cm) on a 1/10 slope.

Offshore wave height was measured at hourly intervals at two locations and found to deviate from the design height in time and across the basin. Shoreline position was measured at 2-hr intervals at 0.25-m spacing alongshore. Shoreline positions at 4 and 18 hr were used to calibrate and verify the numerical model and provide a base model arrangement with which different input conditions could be examined. Breaking wave height was measured at the beginning and end of each case at 0.5-m intervals alongshore.

The groins were made of small cement blocks and were high and impermeable to the waves. The groins were located 6 m apart, centered at $x = 2$, 8, and 14 m. These locations are named A, B, and C, respectively. The groins extended 1.8 m seaward of the average initial shoreline and extended landward to meet the basin wall, so no bypassing could occur landward when the shoreline eroded. The seaward ends of the groins were at a depth of 10 cm. At the seaward end of the groins, the breakwaters rested on a foundation of gravel to prevent subsidence and were made of three layers of tetrapods that were assumed here to allow wave transmission in the numerical simulation presented here. The breakwaters were 1.6 m long and centered on the same lines as the groins, $x = 2$, 8, and 14 m. There was 1.2 m between the far ends of the two outer breakwaters and the basin walls. The design wave height was $H_o = 5.8$ cm in the horizontal section (depth $h =$ 40 cm), and period $T = 1.2$ sec, giving $H_o/L_o = 0.027$, where L_o = deep-water wavelength.

Because the waves, sand, and beach in the physical model tests were almost identical for the three cases, it was appropriate to specify the same values for the calibration parameters found in the previous study (Hanson and Kraus 1991).

In accordance with previous experience, modeling results for the groin configuration were sensitive to changes in the K_1-value, but insensitive to changes in the K_2-value. This result implies that obliquely incident breaking waves account for most of the alongshore sand transport. In contrast, the DBW configuration was more sensitive to changes in the K_2-value. Thus, consideration of Cases 1 and 3 in the calibration and verification procedure facilitates determination of optimum values of K_1 and K_2. The closure depth for GENESIS was taken to be 24 cm by inspection of beach profile change in the physical model. A longshore grid interval of Δx = 25 cm and time step Δt = 18 sec were specified in an explicit solution scheme version of GENESIS. In the DBW configuration, after numerical testing, transmission coefficients (Hanson and Kraus 1990) were taken as 0.05, 0.05, and 0.08, respectively, from left to right .

For verification of GENESIS, shoreline positions at 4 and 18 hr were examined in Cases 1 and 3 as shown in Fig. 3. Values of the transport parameters determined in calibration of Cases 1 and 3 were K_1 = 0.3 and K_2 = 0.15. Trends in shoreline response between cases are well described, as is the offset in shoreline position as responds to wave direction. The tilt in trend of the shoreline, as shown by the positions of the tips of the salients, results from the lateral boundary conditions, producing complete sand starvation on the right side and complete impoundment on the left side. The magnitude of the change is also well reproduced. The center and left portions of the shoreline show good agreement between the physical and numerical models. However, in the right-hand portion of the basin the agreement is more qualitative than quantitative, believed to owe to existence of a complex wave field near the basin wall in the physical model.

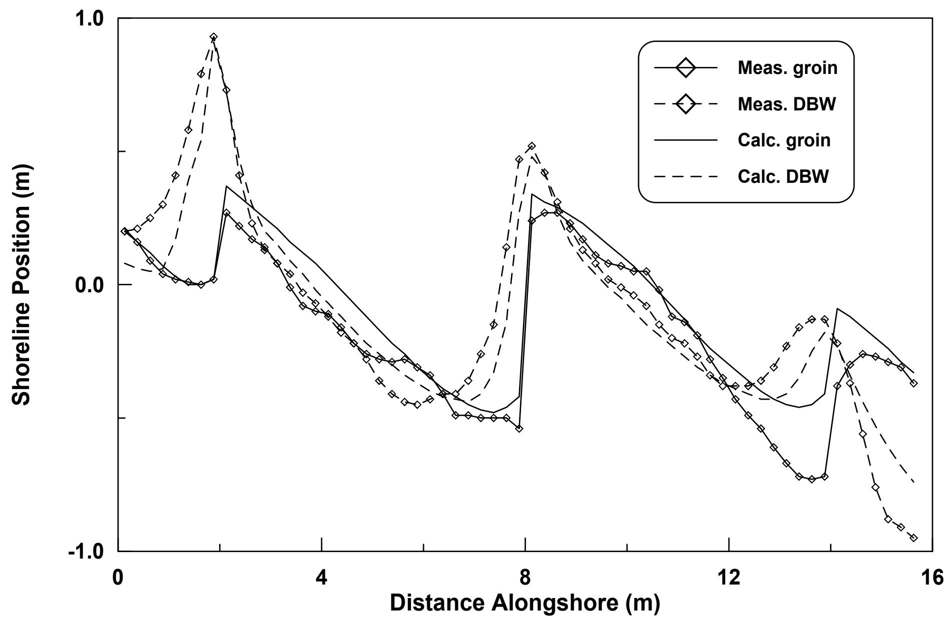

Fig. 3. Result of model verification of Cases 1 and 3.

Case 4 was simulated with K-values left unchanged. The offshore wave height was measured at hourly intervals. Based on the two readings, a linear variation in wave height alongshore was calculated every hour to serve as input for the simulations. The wave transformation from the offshore region to breaking was calculated internally in GENESIS. The measured breaking wave height at the beginning of the test was compared to that calculated by the model.

Results for Case 4 are shown in Fig. 4 where the measured and interpolated offshore wave heights are also displayed.

There is good overall agreement between measured and calculated breaking wave height, especially in the gap between structures. Model validation for this case is shown in Fig. 5 for which shoreline positions at 1 and 18 hr were used. The left-hand salient (A) is well predicted, whereas the other two salients (B and C) are somewhat over-predicted.

Some of the discrepancy in shoreline position is attributed to uncontrollable problems in the physical model, such as slumping of the beach and presence of a basin circulation. Also, rip currents expected to appear in the physical model and in the field are not represented in GENESIS. Thus, both types of models have limitations. As a whole, replication of the physical model behavior is considered good.

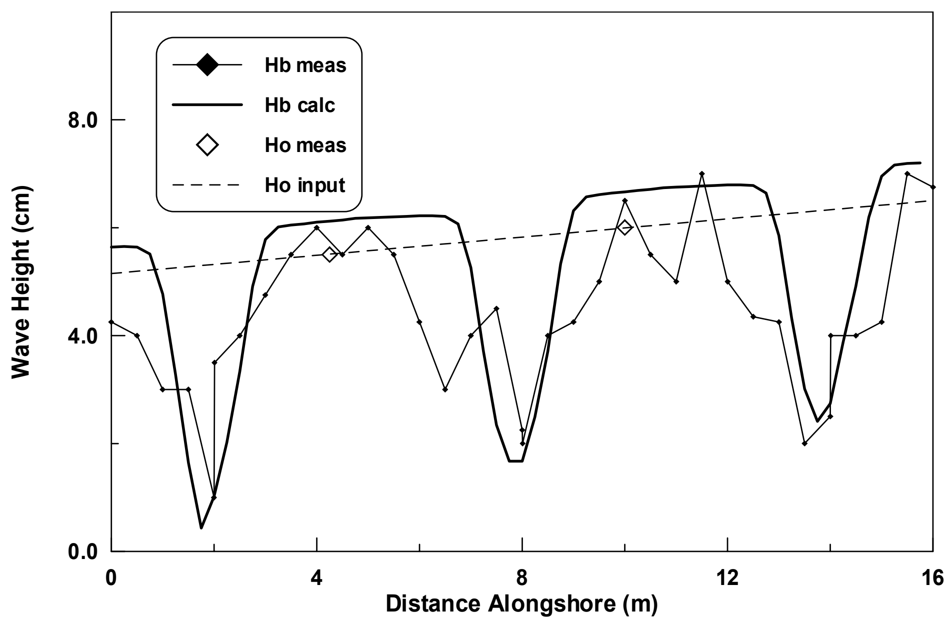

Fig. 4. Alongshore distribution of wave height for Case 4.

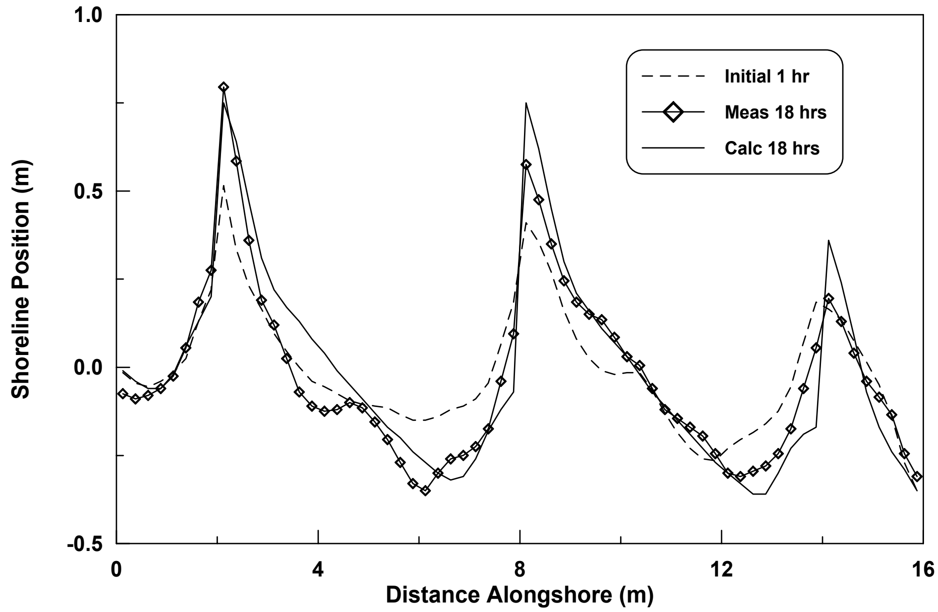

Fig. 5. Result of model validation for Case 4.

Sensitivity Analyses. Encouraged by the above results, it was decided that the physical model layout could serve as a basis in a sensitivity analysis for examining numerical model performance. Three groups of analysis tests were conducted through variation of wave height, wave direction, and model boundary conditions.

As seen from Fig 4, tombolos never developed in the physical model. In GENESIS, while keeping other values unchanged, the wave height was gradually increased to produce tombolos. For wave heights twice as large as in the physical model, tombolos were developed in GENESIS as illustrated in Fig. 6 on the up-drift side of the two T-head groins in the left side of the model (A and B). Up-drift of the right-most groin (C) there was not enough sand to form a tombolo. In addition, a simulation was performed with wave heights half of the original. As seen in the figure, the reduced wave height gave only modest shoreline change.

For varying incident wave direction, the model performed consistently. In addition to the original wave direction of 14 deg, simulations were made for directions of -28 and +14 deg. One simulation was also made for wave angles varying sinusoidally between -14 and +14 deg, completing one full variation period over one hour. As seen in Fig. 7, tombolos did not form, irrespective of the wave angle.

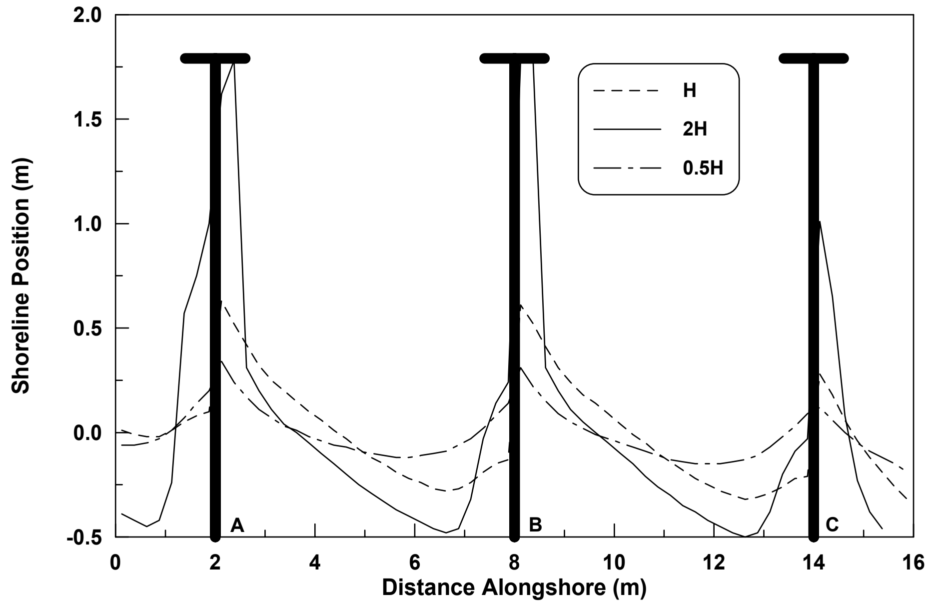

Fig. 6. Calculated shoreline response for varying wave height.

Tombolo Development Keeping all other values as those describing the physical model, the wave height was doubled in two GENESIS runs for 40 hr to illustrate the development of tombolos. In addition, a gated boundary condition was used, allowing sand to get into the system but not out. The first run was made for the T-configuration in Case 4, the second for the DBW configuration in Case 3.

Starting with the measured shoreline after 1 hr in Case 4, a tombolo developed on the up-drift side of Groin A after an additional 2 hr (Fig. 8). As shown in the sensitivity analysis above, this tombolo would never have developed if the boundary had been closed in GENESIS, as it is in the physical model. By allowing sand to enter over the boundary there sufficient material flowing into the system to build a tombolo. After 5 hr, all three T-heads developed tombolos on their up-drift sides.

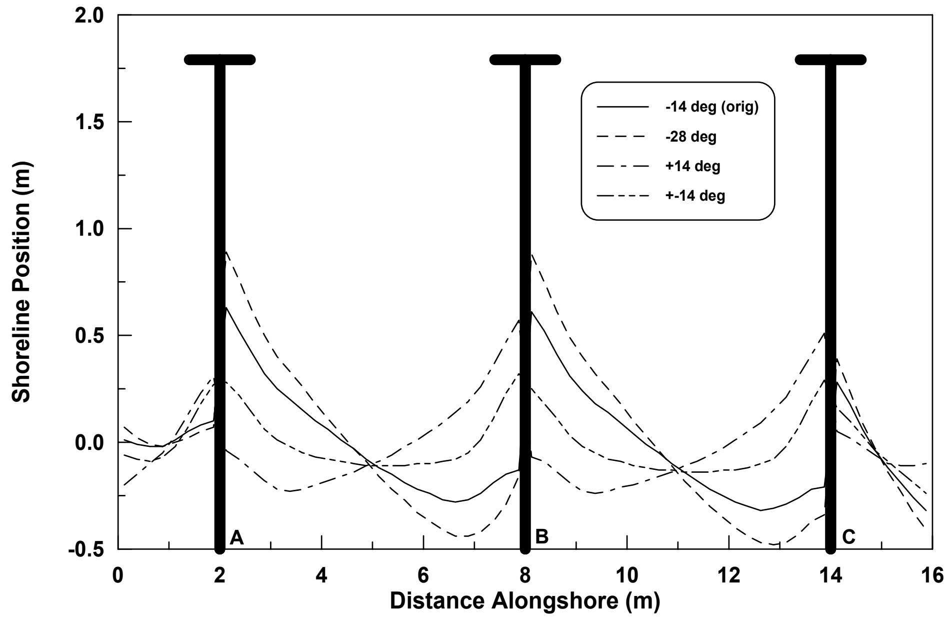

Fig. 7. Calculated shoreline response for varying wave direction.

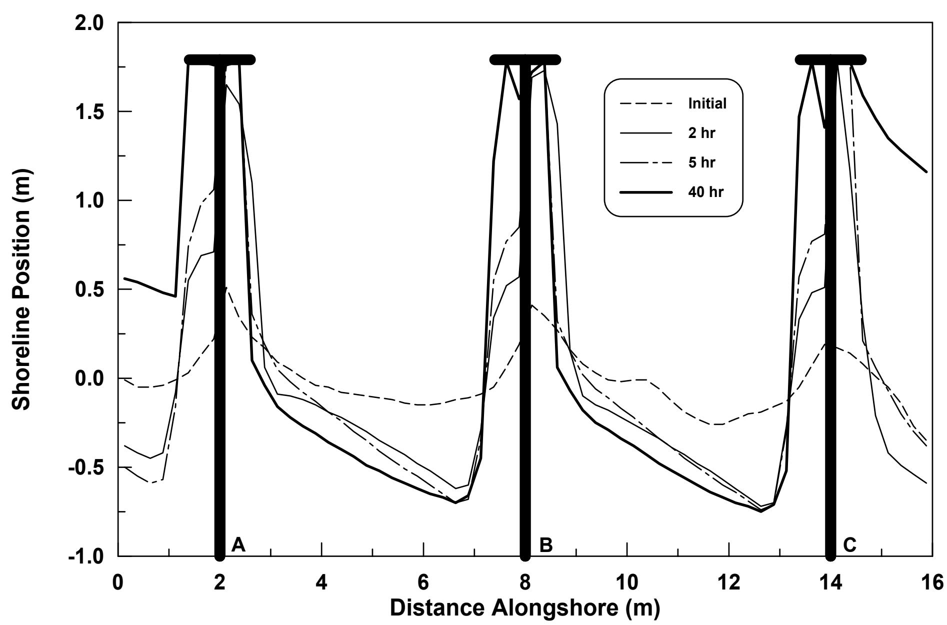

Fig. 8. Calculated evolution of tombolos near T-head groins.

On the down-drift side of the groins sand continued to build out, but the shoreline not yet reached the T-head. On the down-drift side of the structures a tombolo first formed at Groin A and then last at Groin C, thus in opposite order to the pattern on the up-drift side. After 40 hr all three groins had developed tombolos on both sides. Substantial accretion occurred in the areas between Groins A and C and the lateral boundaries, respectively.

The above simulation was repeated with the shore-normal part of the T-groin removed, leaving only the detached breakwaters. The result of this simulation is displayed in Fig. 9. After 2 hr, tombolos did not form, as in the T-groin case. After 5 hr, DBWs A and B developed tonmbolos. At 40 hr, the tombolos had continued to grow on the down-drift sides. In addition, a considerable amount of sand accreted between the DBWs and the model boundaries.

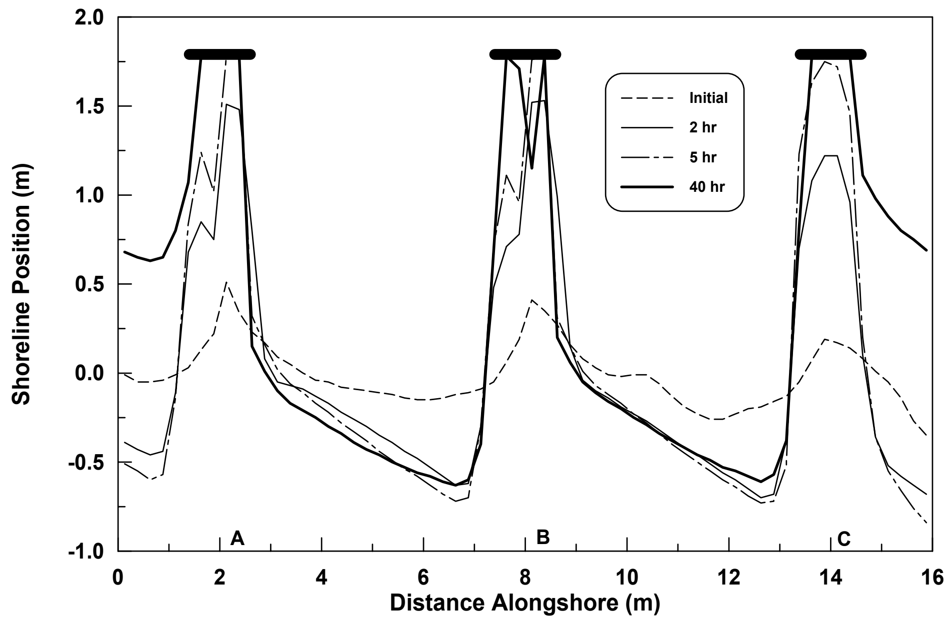

Fig 9. Temporal evolution of tombolos near DBWs.

Calculations for the T-head and the DBW case are shown in Fig. 10. Because of blockage by the groins, virtually all sand that enters into the model over the lateral boundaries remains in the area between the lateral groins and the model boundares throughout the simulation. In the DBW case this sand moved further into the areas between the structures. Thus, the T-head case shows more sand in the areas outside the structures, whereas the DBW case shows more sand between the structures. The total volume is, however, roughly the same for the two cases.

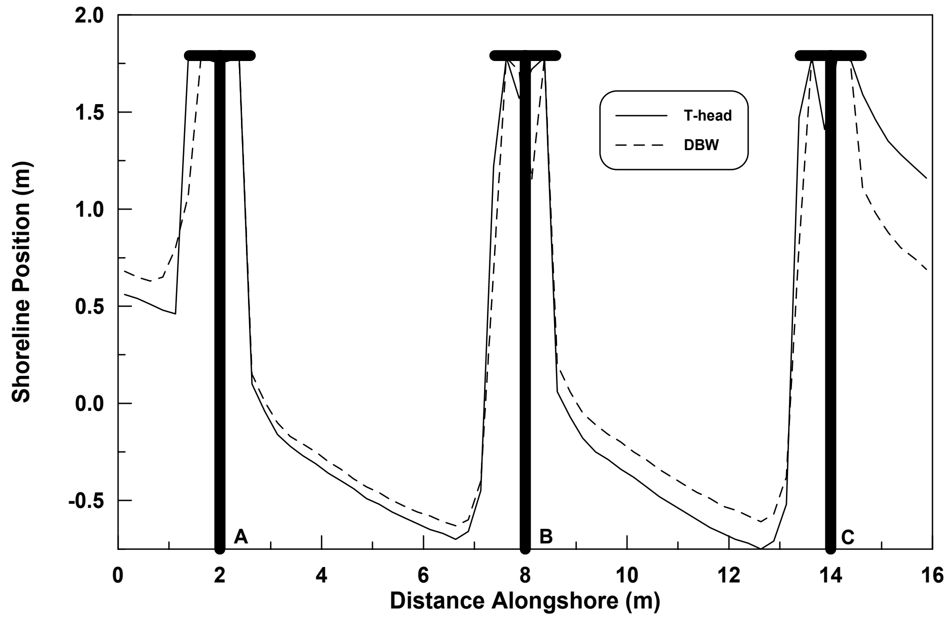

Fig. 10. Comparison of shoreline response inside of T-head groins and DBWs.

CONCLUDING DISCUSSION

This paper has discussed and demonstrated a new capability being implemented in the GENESIS model. Comparisons with the physical model experiments of Hashimoto et al. (1981) indicated that the improved algorithm for representation of T-head groins is working properly.

ACKNOWLEDGMENTS

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